High-efficiency solar cells for large-scale electricity generation

Sarah Kurtz, Jerry Olson, John Geisz, Daniel Friedman, Willliam McMahon, Aaron Ptak, Mark Wanlass, Alan Kibbler, Charlene Kramer, Kris Bertness, Scott Ward, Anna Duda, Michelle Young, Jeff Carapella, Myles Steiner

Dozens of others at Spectrolab, Emcore, and elsewhere

September 26, 2008

UC Merced Solar Symposium

Outline

- Solar is growing very fast
- Optical concentration
  - Reduces semiconductor material
  - Allows use of more efficient (expensive) cells
- The physics high-efficiency solar cells
  - Why using multiple junctions increases efficiency
  - Success of GaInP/Ga(In)As/Ge cell
  - New designs (GaInP/GaInAs/GaInAs) reach 40.8%
- Potential for large-scale solar electricity generation


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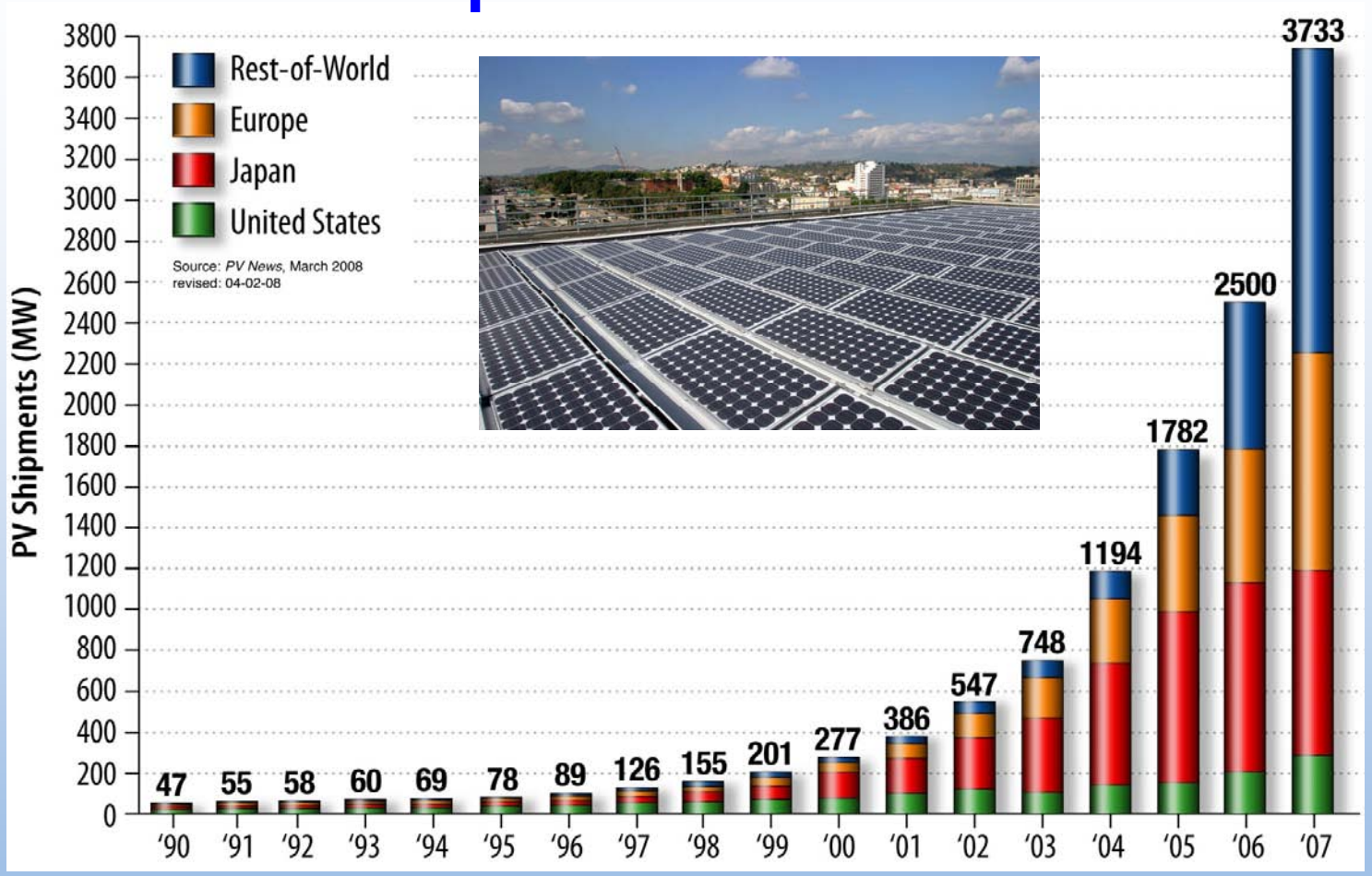
Growth of photovoltaic industry

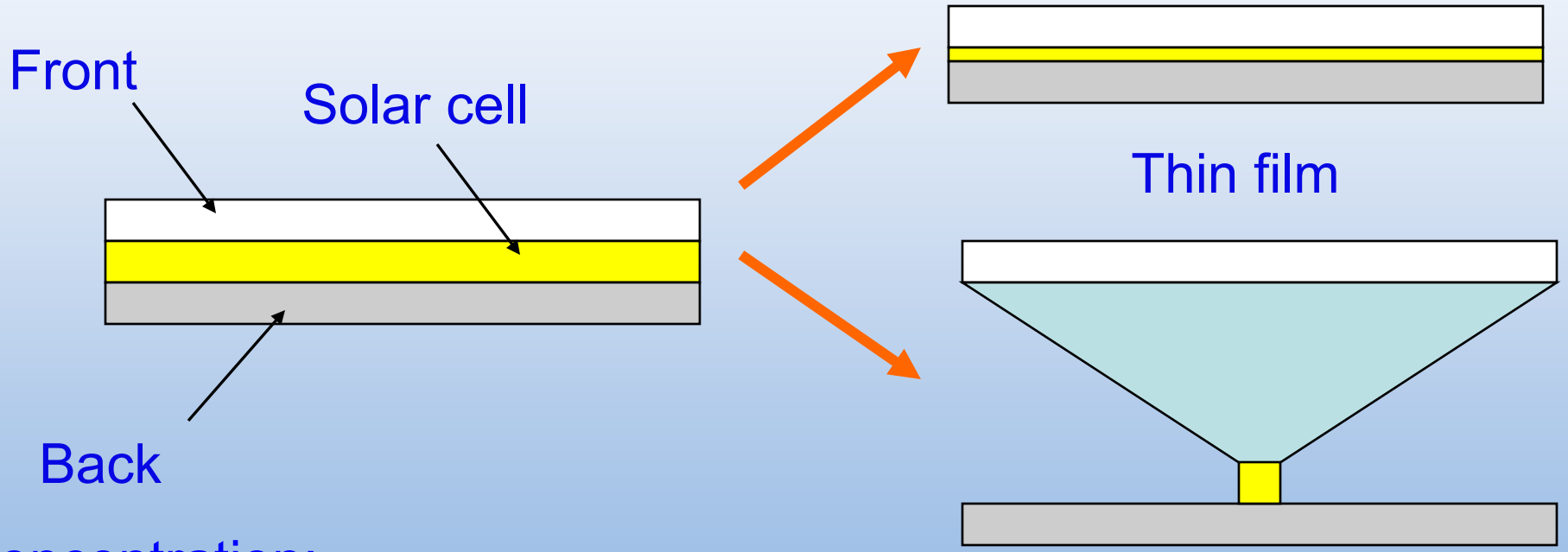


~0.1% of electricity now comes from solar - extrapolates to > 5% in 2020

competitive with conventional electricity for 0.1% - 1% of market; more in future

Rogol, PHOTON International August 2007, p 112.

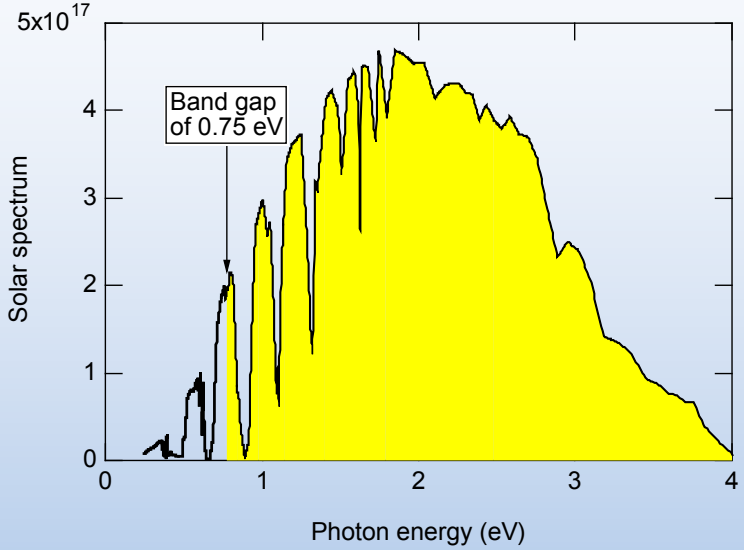
Industry growth is currently constrained by Si availability, motivating us to reduce semiconductor material



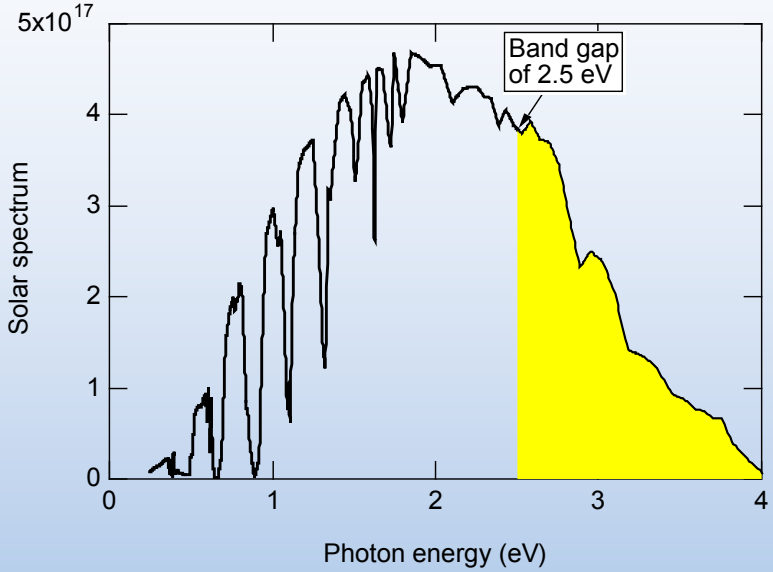
Concentration:

1. Reduces semiconductor use
2. Allows use of higher efficiency cell (higher system efficiency)

Why multijunction?
Power = Current X Voltage



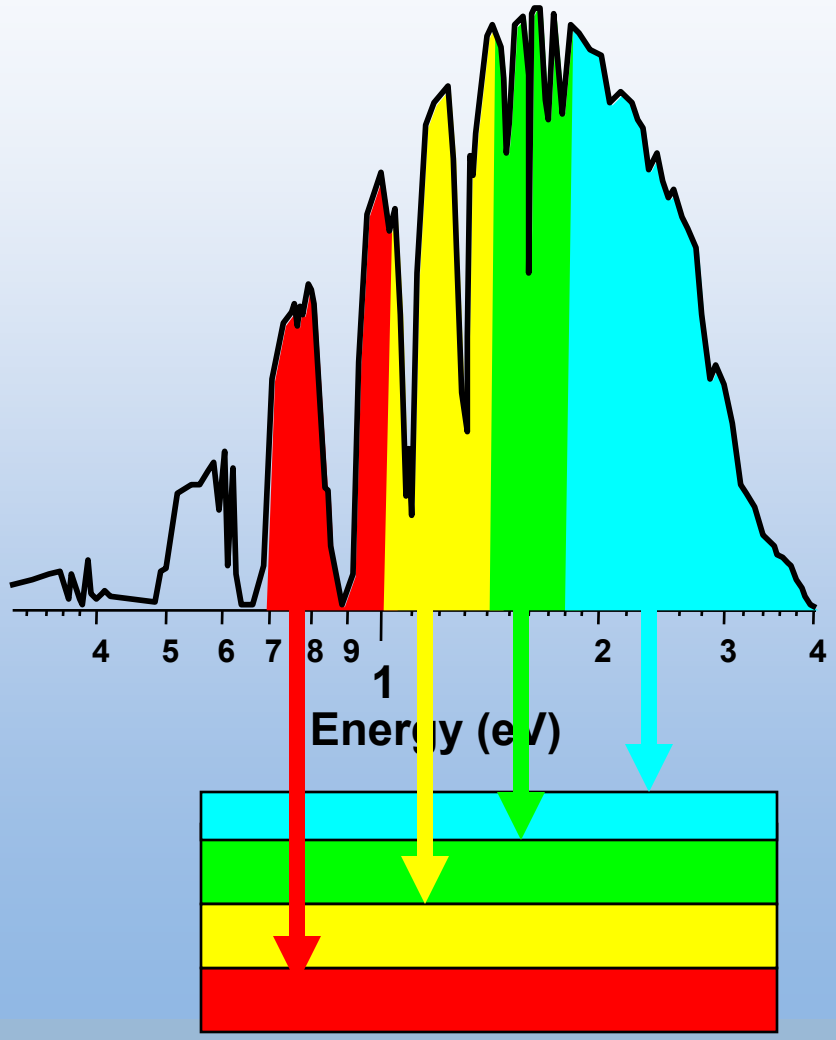
High current,
but low voltage
Excess energy lost to heat



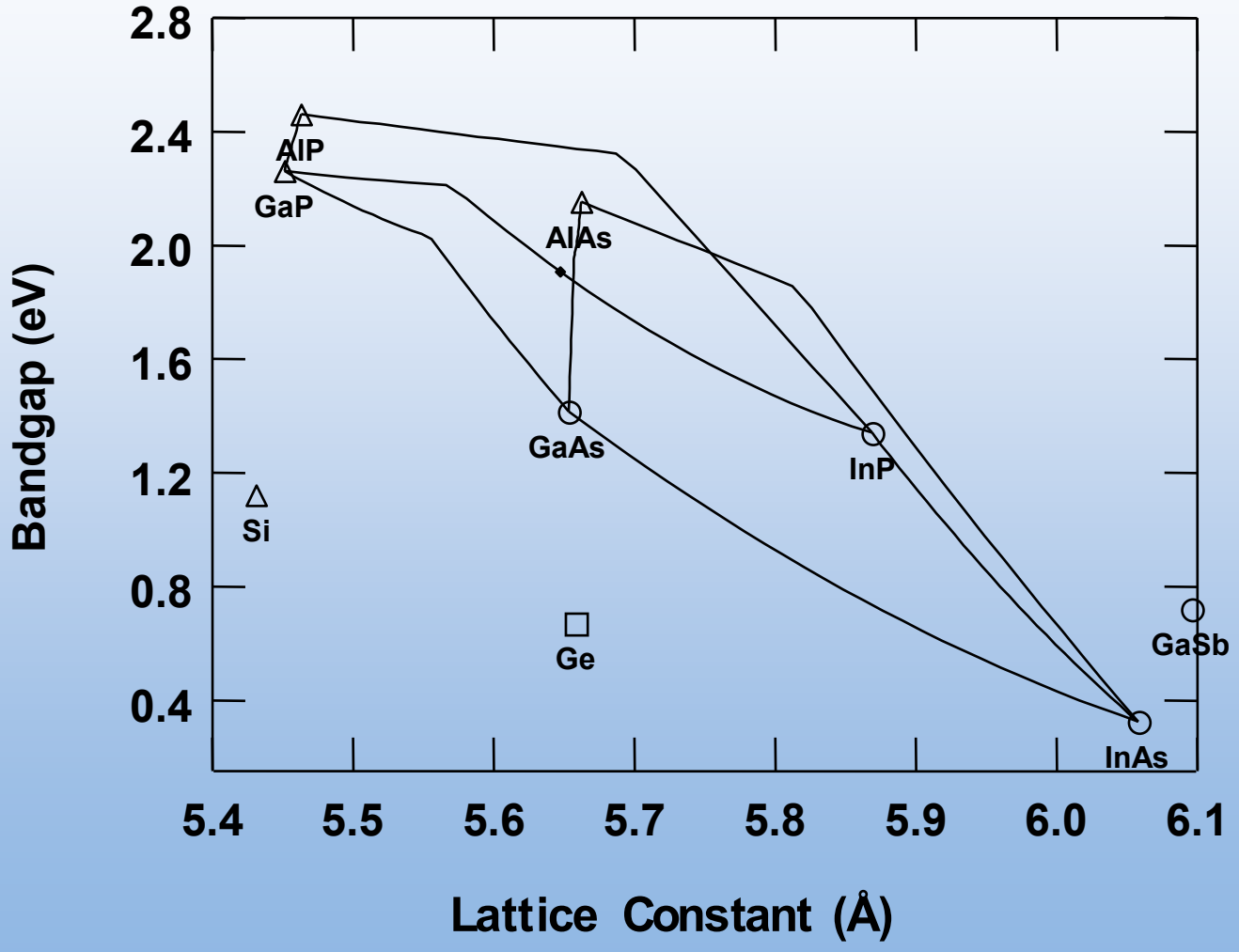
High voltage,
but low current
Subbandgap light is lost

Highest efficiency: Absorb each color of light with a material that has a band gap equal to the photon energy

Multijunction cells use multiple materials to match the solar spectrum

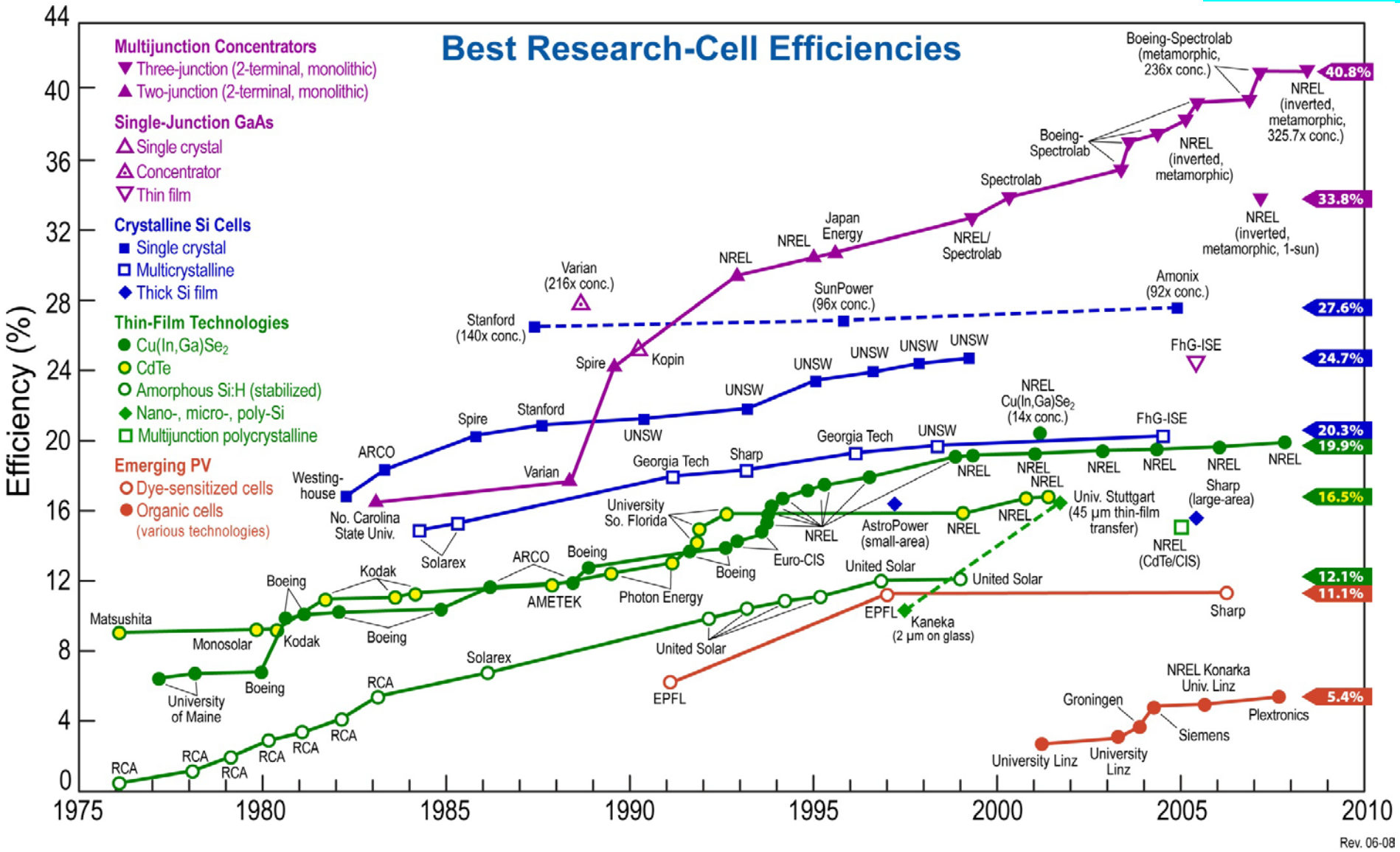


Multijunction cells use multiple materials - many possible combinations



Champion solar-cell efficiencies - Multijunction achieves highest

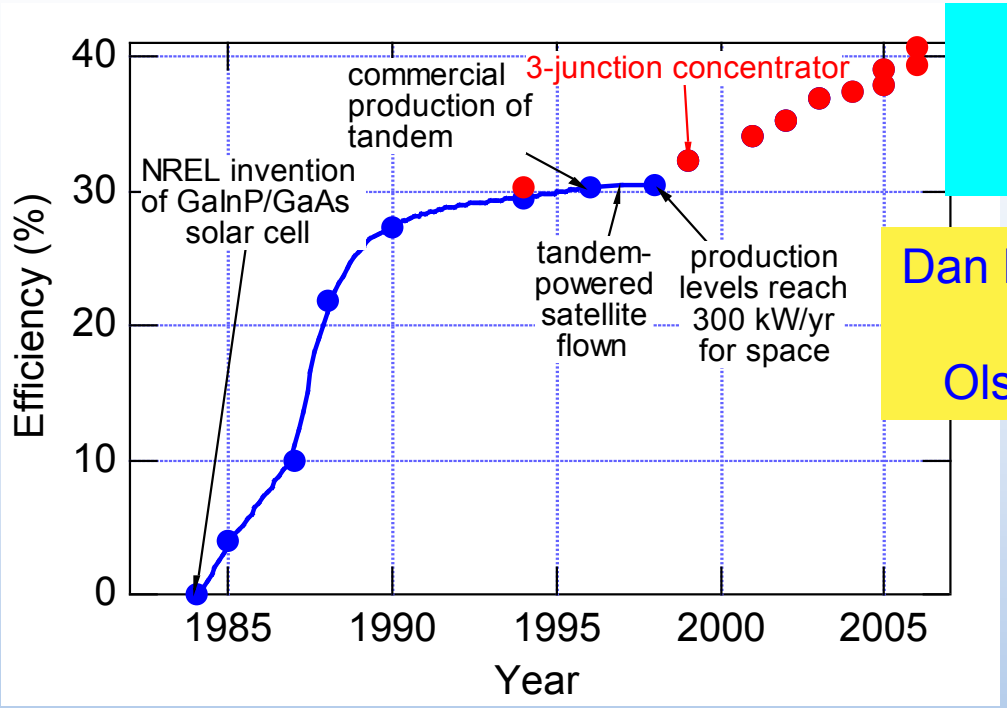
40.8%
Geisz
(NREL)



Historical perspective

- In 1984:
  - Multijunction approach is predicted to achieve higher efficiency
  - AlGaAs/GaAs is considered lowest-risk approach to implementing multijunction
  - Lattice mismatched combinations considered higher risk approach
  - GaInP alloys were “known” to be unstable
- Jerry Olson proposed GaInP/GaAs

Success of multijunction cells using GaInP



40.8%
Geisz
2008

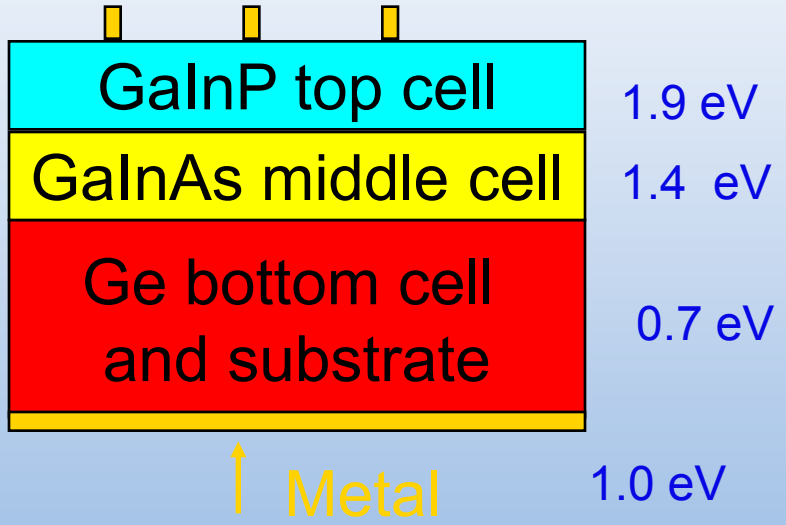
Dan David Prize
2007
Olson, Kurtz

Mars Rover powered by multijunction cells

This very successful space cell is currently being engineered into systems for terrestrial use

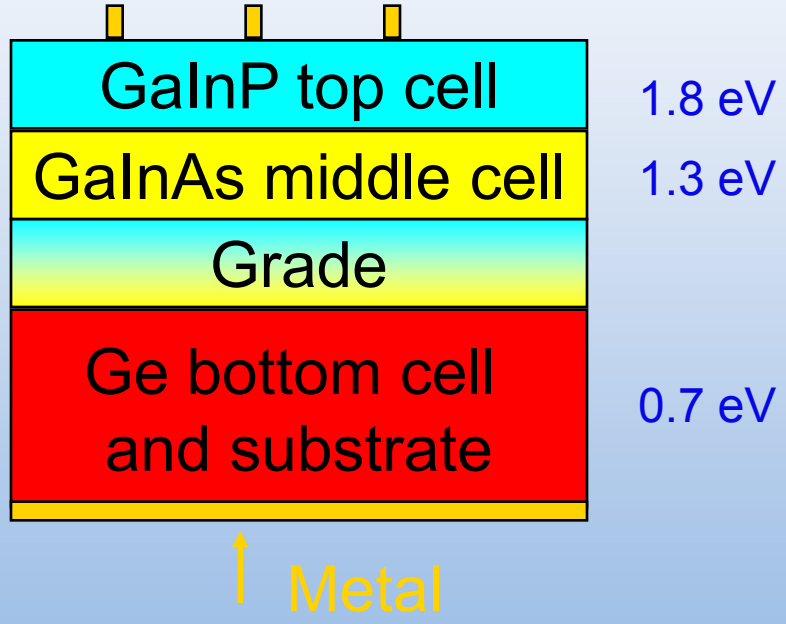
High-efficiency GaInP/Ga(In)As/Ge cells

Lattice matched



40.4% King, 2006

Lattice mismatched



40.7% King, 2006

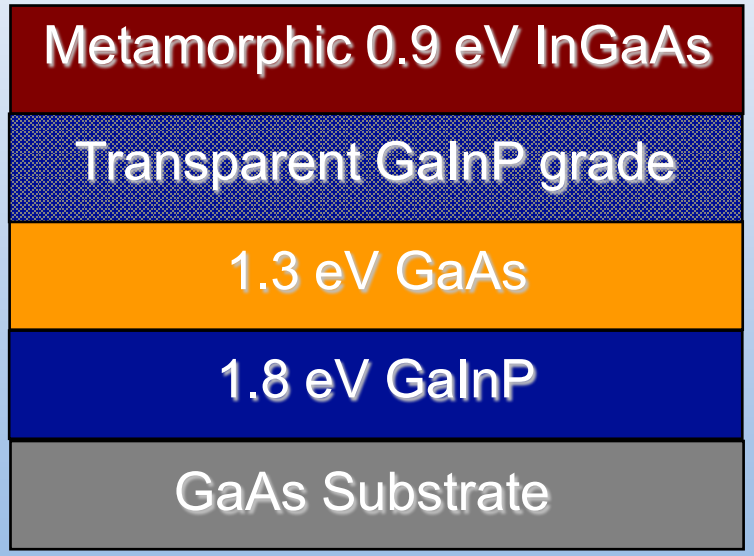
New research: from 40% to 50%

Inverted GaInP/Ga(In)As/GaInAs solar cell champion: 40.8%

- MOVPE growth on GaAs substrate.
- Inverted structure.
- Mounted on Si or glass handle.
- GaAs substrate selectively removed.
- Front-side processing completes cell.

Advantages:

- Higher efficiency
- Reuse of substrate or use of impure substrate can reduce cost



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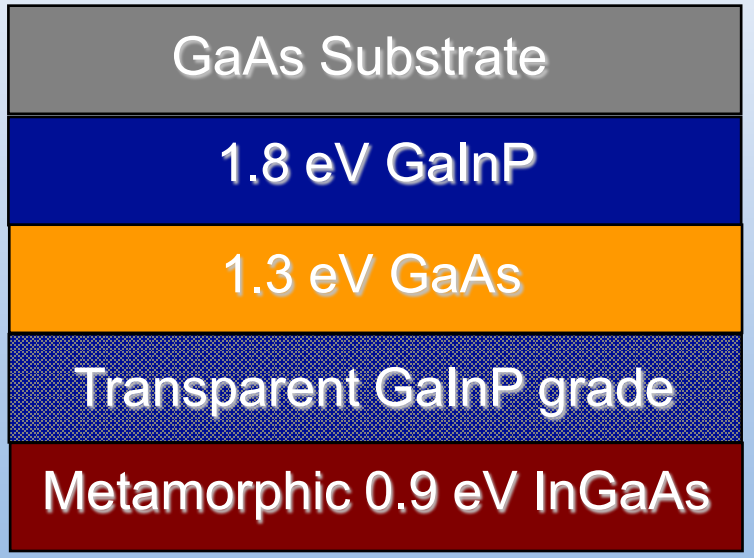

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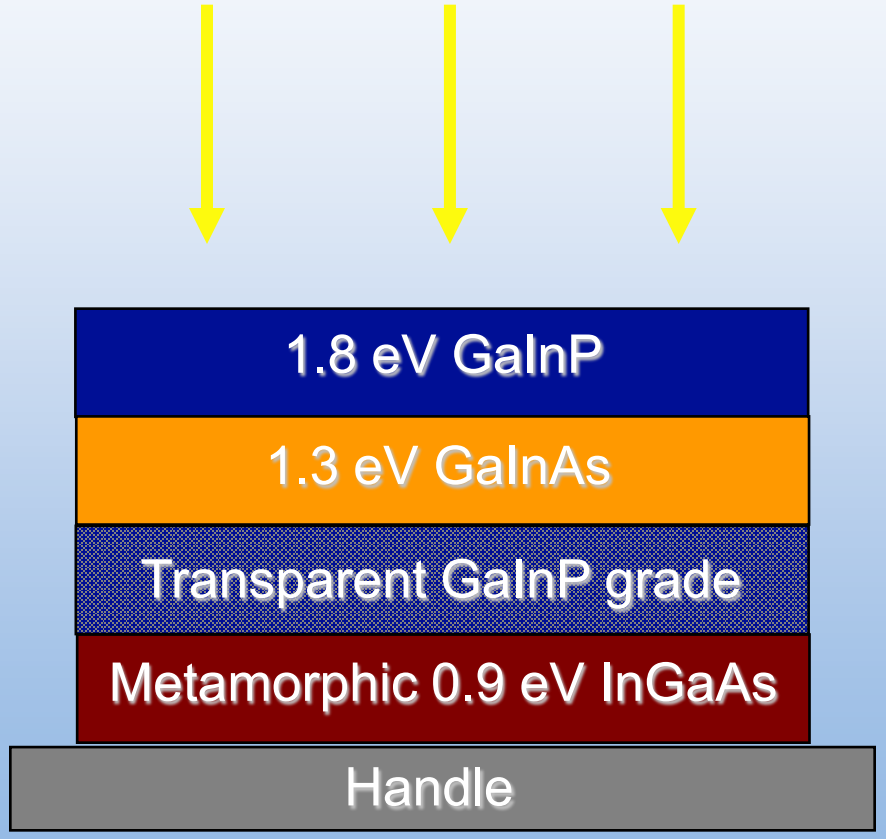


Solar for large-scale electricity generation

Convergence of utilities and photovoltaic companies?

- Recent trends
  - Multi megawatt systems becoming common
  - Dominance of building integration is no longer assumed
  - More systems are ground mounted
  - More systems are tracked
- Interest from utilities is growing

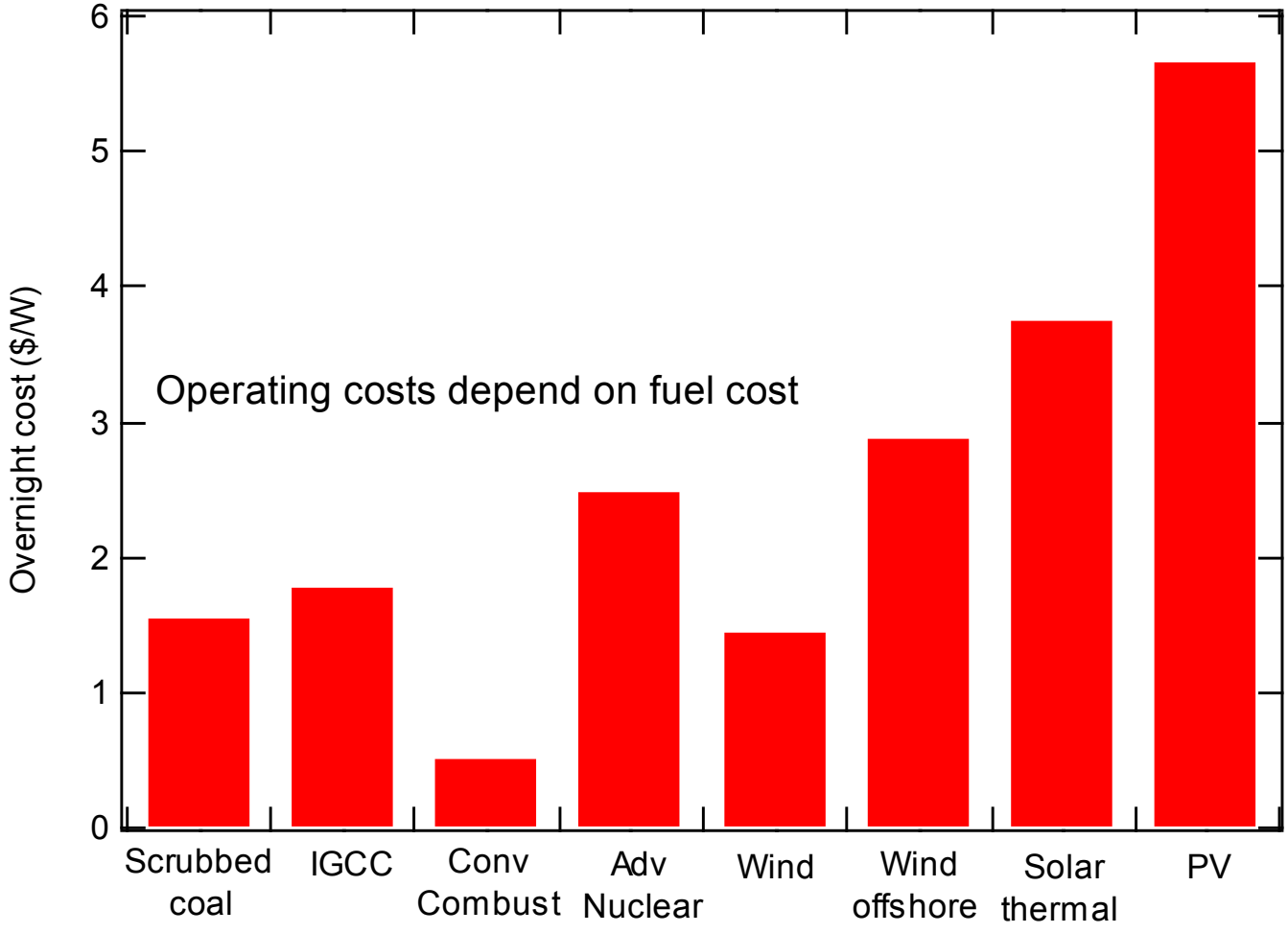
How can multijunction cells make a difference?

- Use less semiconductor material
  - Capital investment can be less
  - If other costs can be reduced, then may be able to achieve very low cost
- High efficiency has potential to generate the most electricity per area
- Commercial investment involves more than 50 companies with total investment on order of $1B

- Deployment in 2008 expected to be ~ 1 MW

Electricity costs are going up, but PV is still expensive

source: http://www.eia.doe.gov/oiaf/aeo/assumption/pdf/electricity.pdf#page=3



Summary

- Photovoltaic industry is doubling every two years
- Using concentration may help the solar industry grow even faster
- Multijunction cells provide the path to high efficiency; > 40% and are still increasing
- Solar industry is moving into large-scale, utility applications; multijunction cells may hasten this trend

Flying high with high efficiency

Cells from Mars rover may soon provide electricity on earth

High efficiency, low cost, ideal for large systems